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(54) **Heart-synchronized pulsed laser system**

Mit dem Herz synchronisiertes Impulslasersystem

Système de laser pulsé, synchronisé avec le coeur

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Description

FIELD OF INVENTION

This invention relates to a heart-synchronized pulsed laser system, and more particularly to such a system which operates on a beating heart between the R and T waves of the electrocardiogram (ECG) signal.

RELATED CASES

This application is related to the following applications having common inventors and assignee and filed on even date herewith:

"Long Pulse, Fast Flow Laser System and Method", by Robert I. Rudko (Docket No. LE-110J);

"Handpiece for Transmyocardial Vascularization Heart-Synchronized Pulsed Laser System", by Robert I. Rudko (Docket No. LE-111J); and

"Heart-Synchronized Vacuum-Assisted Pulsed Laser System and Method", by Robert I. Rudko (Docket No. LE-112J).

Another prior art document is US-4,788,975 which discloses the features comprised in the preamble of claim 1.

BACKGROUND OF THE INVENTION

The heart muscle receives its blood supply from the coronary artery, which feeds out and around into the outside of the heart muscle. Some time ago it was noticed that reptilian hearts had no arterial supply to the heart muscle. Rather, the reptilian heart blood supply was delivered through the inside wall of the heart directly to the heart muscle. The thought occurred that this could be an alternative to the heart bypass technique which can usually be applied to a patient no more than twice: after two bypass operations the risks outweigh the benefits and the patient is generally without further recourse . In an attempt to imitate the reptilian condition, tiny holes were made in mammalian hearts with hot wires or needles but this met with limited success. Although the holes healed from the outside and did allow for some internal blood delivery, the holes soon healed over entirely and cut off the blood supply. The protocol was then developed using a laser to make the holes and this met with much greater success. This technique is known as transmyocardial revascularization (TMR).

However, the laser technique introduced a host of new problems. The heart is extremely sensitive to a laser pulse at certain times during its cycle. A laser pulse striking the heart at the T time of the ECG wave, for example, could cause the heart to fibrillate and result in heart failure. If the heart is stopped during the procedure this problem can be avoided. But stopping the heart requires cooling the heart and connecting the patient to a heart-lung machine with all the attendant increased risks that this brings including prolonged recovery times. A beating heart, on the other hand, is difficult to administer this technique to because as the heart contracts and expands the surface may not remain normal to the laser beam, the heart wall changes distance from the focus of the beam, and the thickness of the wall changes so that the positioning of the laser handpiece and the power of the beam required are varying and unpredictable. This makes precise location of laser beam on the heart difficult so that not only will the holes not be properly located, but other areas of the heart which should not be struck may well be struck. Further, when the technique requires stopping the heart the chest must be cut open including cutting the sternum, which is especially risky because the sternum is a primary source of red blood cells.

SUMMARY OF INVENTION

It is therefore an object of this invention to provide a laser system for performing transmyocardial revascularization on a beating heart.

It is a further object of this invention to provide such a laser system which is synchronized to operate at a specific time in the heart's beating cycle when accuracy is enhanced and risks are reduced.

It is a further object of this invention to provide such a laser system which is synchronized to operate between the R and T waves of the heart's ECG.

It is a further object of this invention to provide such a laser system which provides shorter pulses that interfere less with the heart function and make cleaner holes.

It is a further object of this invention to provide such a laser system which times the laser pulses to occur when the heart surface is relatively stable to enhance the accuracy of laser aiming and focusing and minimize the risk of striking an undesirable part of the heart.

It is a further object of this invention to provide such a laser system which times the laser pulses to occur when the heart wall is at a point in its cycle when it is electrically least sensitive to interference with its functioning.

It is a further object of this invention to provide such a laser system which substantially reduces the chance of inducing fibrillation.

It is a further object of this invention which provides such a laser system which is safe, requires no attachment of the patient to a heart-lung machine, no cooling of the heart, and no opening of the sternum.

It is a further object of this invention to provide such a laser system which requires only a simple incision between the patient's ribs and results in less trauma, faster recovery and less blood loss.

The invention results from the realization that a pulsed laser system can be achieved for operating on a beating heart accurately, with minimal interference to the heart and minimal risk to the patient by synchronizing the pulsing of the laser to the ECG of the heart so that laser pulses can be administered to the heart only during the moment when the heart is most still, least sensitive electrically, during the period between the R and the T waves of the ECG.

This invention features a heart-synchronized pulsed laser system including a laser system. There are means for sensing the contraction and expansion of a beating heart which is to be synchronized with the laser. There are means, responsive to the means for sensing, for generating a trigger pulse in response to the ECG signal, as well as means for positioning the leading edge of the trigger pulse during the contraction and expansion cycle of the heartbeat, and means for defining the width of a trigger pulse to occur during the heartbeat cycle. There are means responsive to the trigger pulse for firing the laser to strike the beating heart at the selected time indicated by the trigger pulse position and for the period indicated by the width of the trigger pulse.

In a preferred embodiment, the means for sensing the contraction and expansion includes means for sensing the ECG signal of the beating heart. There is a laser delivery system which may include an articulated beam delivery arm or a fiber optic element. The means for sensing the ECG signal of the beating heart may be an ECG unit and the means for generating the trigger pulse may do so in response to the R wave of the ECG. In the means for positioning, the leading edge of the trigger pulse may position the trigger pulse between the R and the T waves of the ECG. The means for defining the pulse width of the trigger pulse may define a pulse width which occurs in the period between the R and the T waves of the ECG.

The means for generating may include a marker pulse circuit for generating a specific time in a heartbeat cycle of the ECG for providing a marker pulse representative of that time. The means for generating may further include a trigger pulse circuit responsive to the marker pulse circuit for providing a trigger pulse whose position in the heartbeat cycle is a function of the specific time in the cycle represented by the marker pulse. The trigger pulse circuit may include means for delaying the marker pulse to locate it at a selected position relative to its initial position in the heartbeat cycle, and means for adjusting the duration of the marker pulse to a selected time to create the trigger pulse of the selected position and width.

The means for firing may include gate means for inhibiting delivery of the trigger pulse to the laser and may further include switch means for enabling the gate means to deliver the trigger pulse to the laser. There may be an arming circuit for further inhibiting delivery of the trigger pulse to the laser, and arming switch means for enabling the arming circuit to deliver the trigger pulse to the laser.

DISCLOSURE OF PREFERRED EMBODIMENT

Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

Fig. 1 is a schematic block diagram of a heart-synchronized pulsed laser system according to this invention;

Fig. 2 is a more detailed diagram of the system of Fig. 1;

Fig. 3 illustrates the ECG signal, marker pulse, trigger pulse and firing pulse waveforms occurring in the heart-synchronized pulsed laser system described in Figs. 1 and 2;

Fig. 4 is an illustration of a touch-sensitive monitor that may be used in conjunction with the system of Figs. 1 and 2;

Figs. 5A and B are more detailed schematic diagrams of the trigger pulse circuit, pulse positioning circuit, pulse width circuit and laser firing circuit of Fig. 2.

This invention may be accomplished in a heart-synchronized pulsed laser system having a laser and a laser beam delivery system. The laser is typically a pulsed 50 Joules CO_2 laser. The laser beam delivery system may be an articulated optical arm or a fiber optic element with a suitable handpiece or terminal optics at the distal end for delivering the laser beam for perforating the heart. There is some means for sensing the electrocardiogram signal of the beating heart to be synchronized with the laser. This may be a standard ECG device such as obtainable from Hewlett-Packard Company. The system uses some means for generating a trigger pulse in response to the ECG signal. Typically the trigger pulse is a function of the R wave of the heartbeat cycle generated by the conventional ECG equipment. The heartbeat cycle has four distinct waveforms, the Q, the R, the S, and the T. There are means for setting the beginning of the trigger pulse so that it occurs in the proper time relationship to the R wave and ends before the T wave to avoid interference with the electrical characteristics of the beating heart. The pulse positioning circuit locates the leading edge of the trigger pulse and a pulse width circuit determines the width so that it extends over only the necessary and safe duration of the heartbeat cycle. The trigger pulse is passed to a laser firing circuit, which then operates the laser to produce a pulsed laser beam to the delivery system which the surgeon aims precisely at the beating heart preferably during the time between the R and T waves of the heartbeat cycle where the heart is most static, and the accuracy is most assured.

The trigger generator may include a marker pulse circuit for detecting a specific time in the heartbeat cycle of the ECG signal and providing a marker pulse representative of that time. The time may be when the R wave crosses a particular threshold or some time related to that time. The marker pulse circuit may be built in as a part of the readily obtainable ECG unit such as a type HP78352A obtainable from Hewlett-Packard Company. The trigger pulse circuit, also is the means for generating the trigger pulse, responds to the marker pulse circuit to provide a trigger pulse whose position in the heartbeat cycle is a function of that specific time in the cycle rep-

resented by the marker pulse. The trigger pulse circuit typically includes means for delaying the marker pulse to locate it at a selected position relative to its initial position in the heartbeat cycle, and also contains means for adjusting the delay of the marker pulse to a selected time to create the trigger pulse of the selected position and width. The position of the trigger pulse and its width may be adjusted by a pulse positioning circuit and a pulse width circuit. The laser firing circuit includes a gate which inhibits delivery of the trigger pulse to the laser unless a foot switch is enabled by the surgeon when he is ready to make a hole in the heart. There is also an arming circuit which further inhibits delivery of the trigger pulse to the laser, even if the surgeon steps on the foot switch unless that arming switch has been actuated. If the arming switch is actuated and the foot switch is depressed, the next trigger pulse will be directed to fire the laser and provide a pulsed laser beam.

There is shown in Fig. 1 a heart-synchronized pulsed laser system 10 with electrocardiogram unit 12 connected to a heart 14 which is to undergo the surgery. The ECG signal 16 is delivered to trigger generator 18, which provides a trigger pulse 20 to laser firing circuit 22, which in turn energizes laser unit 24 including a laser power supply and a laser to produce a pulsed laser beam through articulated optical arm 26 into optical handpiece 28 to make a hole 30 in heart 14. The position of trigger pulse 20 in the heartbeat cycle of ECG signal 16 is determined by pulse positioning circuit 32. The width of the pulse 20 and its duration during the heartbeat cycle is determined by pulse width circuit 34. Trigger generator 18 as well as pulse positioning circuit 32 and pulse width circuit 34, may be included as an additional board in a PC or a microprocessor 36, in which case the system can be controlled through the computer keyboard and suitable software. PC 36 and ECG 12 may have separate monitors, or they may have a single monitor 38 which displays both the ECG and information about the trigger pulse 20. Trigger generator 18 may include a marker pulse circuit 50 which provides marker pulse 52 and trigger pulse circuit 54 which responds to marker pulse 52 to create trigger pulse 20. Alternatively, marker pulse circuit 50 is included in the ECG itself in some cases.

This can be better understood with reference to Fig. 3, where ECG signal 16 may be seen as consisting of a series of heartbeat cycles 56a, 56b, 56c each of which contains the waveforms Q, R, S and T. Where waveform R crosses preselected threshold 58, marker pulses 52a, 52b, 52c are created. Trigger pulses 20a, 20b, 20c are then created by trigger pulse circuit 54. The position of the leading edge 60 and the overall width 62 of each trigger pulse 20 is determined, respectively, by pulse positioning circuit 32 and pulse width circuit 34. In response to trigger pulse 20, a firing pulse 64 indicated as 64a, 64b and 64c, Fig. 3, is created to energize laser 24.

In Fig. 2, laser firing circuit 22 is shown to include gate 70 which generally inhibits the delivery of trigger circuit 20 to laser power supply 72 in laser unit 24. The inhibiting effect of gate 70 can be overcome when the surgeon steps on foot switch 74. Trigger pulse 20 is still inhibited, however, by arming circuit 76 which in turn can have its inhibiting effect overcome by the operation of arming switch 78. This double lock on the delivery of trigger pulse 20 to laser power supply 72 ensures that the firing of the laser is truly desired and not accidental. Thus the surgeon must first arm the system by operating arming switch 78 to enable arming circuit 76. Then and only then is he able to pass the next occurring trigger pulse 20 through gate 70 to the laser power supply 72 by actuating his foot switch 74. Also included in laser unit 24 is a standard CO_2laser 80. The output of laser 80 may be delivered through a fiber optic element 26a to handpiece 28.

Monitor 38, Fig. 4, may display both the ECG signal 16 and the display of the delay 84 which has been introduced by pulse positioning circuit 32, Fig. 2, which delay is indicated as one millisecond in Fig. 4. It may also include the pulse width 86 shown as 50 milliseconds selected by the pulse width circuit 34, Fig. 2. Monitor 38 may also include a delay selection switch 88 which when pressed enables one to increase or decrease the delay time by simply touching the up 90 or down 92 arrows on the screen. Pulse width touch switch 94 may be used in the same fashion to adjust the pulse width duration.

Trigger pulse width circuit 54, Fig. 5, may include an anti-false trigger pulse circuit 100 which prevents a false firing or second firing of the system when a firing sequence is already in progress. Also included in trigger pulse circuit 54 is a delay timer 102 and a pulse width timer 104. When marker pulse 52 on line 106 is permitted to pass through anti-false trigger pulse circuit 100, the marker pulse is input on line 108 to delay timer 102. The conjunction of the marker pulse with the input on line 110 from 10 KHz clock 112 causes delay timer 102 to set the position of the leading edge of the trigger pulse. The appearance of the marker pulse on line 108 also is delivered as an enable signal on line 114 to preset pulse width timer 104. When the leading edge position of the trigger pulse has been set by delay timer 102 a signal is provided on line 116 to AND gate 118, which in conjunction with a signal from clock 112 causes the trigger pulse to be expanded to a predetermined width in pulse width timer 104. The specific positioning of the leading edge of the trigger pulse by delay timer 102 is controlled by pulse positioning circuit 32 which is typically a time delay data latch under control of the computer via the data bus 120. Similarly, the duration of the pulse imparted by pulse width timer 104 is controlled by pulse width circuit 34, typically a pulse width time data latch under control of the microprocessor or PC via bus 122. The trigger pulse then is delivered over line 124 to gate 70 which may include simply an AND gate 126.

Arming circuit 76 includes flip-flop 128, inverter 130, and OR gate 132. When arming switch 78 is actuated, the signal to inverter 130 resets flip-flop 128 so that now there is a proper output on line 134 from flip-flop 128 into OR gate 132 as well as the proper input from arming switch 78 on line 136 into OR gate 132. Thus, when next

the trigger pulse arrives on line 124, if the doctor operates the foot switch 74 the pulse will be passed through AND gate 126 and OR gate 132 to pass the trigger pulse on line 140 to laser power supply 72. When the trigger pulse passing through OR gate 132 ends, the clock input to flip-flop 128 is no longer enabled and the output on line 134 ceases so that OR gate 132 is no longer enabled to pass subsequent trigger pulses to line 140 and laser power supply 73.

The anti-false trigger pulse circuit 100 uses a flip-flop 150, two inverters 152 and 154, and two OR gates 156 and 158. When a trigger pulse is supplied on line 124 by pulse width timer 104, it is also simultaneously placed on line 160 which is connected to inverter 154 and to OR gate 156. At the end of the trigger pulse, the proper level appears on line 160 to enable OR gate 156 and to reset flip-flop 150 through inverter 154 and OR gate 158. When flip-flop 150 is reset it provides a second enabling input on line 162 to OR gate 156. Thus when next a marker pulse 52 is delivered on line 106 and passed by inverter 152 to OR gate 156, it is passed to line 108 and thus on to delay timer 102. The marker pulse 52 appearing on line 108 also clocks flip-flop 150 so that the proper signal is no longer on line 162 and AND gate 156 is disabled. Until a reset occurs from the software on line 166 or the end of the trigger pulse level occurs on line 160 no further marker pulses will be passed.

Claims

1. A heart-synchronized pulsed laser system (10) comprising:
   a laser (24);
   means (12) for sensing the contraction and expansion of a beating heart to be synchronized with the laser;
   means (18) responsive to said means for sensing, for generating a trigger pulse (20);
   means (32) for positioning the leading edge of said trigger pulse during the contraction and expansion cycle of the heartbeat;
   characterized in that said system further comprises:
   means (34) for defining the width of the trigger pulse to occur during said heartbeat cycle; and
   means (22), responsive to said trigger pulse (20), for firing said laser to strike the beating heart at the time indicated by the trigger pulse position and for the period indicated by the width of the trigger pulse.

2. The heart-synchronized pulsed laser system of claim 1 in which said laser includes a laser beam delivery system (26,26a,28).

3. The heart-synchronized pulsed laser system of claim 2 in which said laser delivery system includes an articulated beam delivery arm (26).

4. The heart-synchronized pulsed laser system of claim 2 in which said laser delivery system includes a fiber-optic element (26a).

5. The heart-synchronized pulsed laser system of claim 1 in which said means for sensing the contraction and expansion includes means (12) for sensing the ECG signal of the beating heart.

6. The heart-synchronized pulsed laser system of claim 5 in which said means (12) for sensing the ECG signal of the beating heart is an ECG unit.

7. The heart-synchronized pulsed laser system of claim 5 in which said means (18) for generating generates a trigger pulse in response to the R wave of the ECG.

8. The heart-synchronized pulsed laser system of claim 5 in which said means (32) for positioning sets the leading edge of said trigger pulse in the period between the R and T waves of the ECG.

9. The heart-synchronized pulsed laser system of claim 5 in which said means (34) for defining defines the pulse width of said trigger pulse in the period between the R and T waves of the ECG.

10. The heart-synchronized pulsed laser system of claim 5 in which said means for generating includes a marker pulse circuit (50) for detecting a specific time in a heartbeat cycle of the ECG signal and providing a marker pulse representative thereof.

11. The heart-synchronized pulsed laser system of claim 10 in which said means for generating further includes a trigger pulse circuit (54), responsive to said marker pulse circuit (50), for providing a trigger pulse (20) whose position in the heartbeat cycle is a function of said specific time in the cycle represented by said marker pulse.

12. The heart-synchronized pulsed laser system of claim 11 in which said trigger pulse circuit includes means (88) for delaying said marker pulse to locate it at a selected position relative to its initial position in the heartbeat cycle, and means (94) for adjusting the duration of the marker pulse to a selected time to create said trigger pulse of the selected position and width.

13. The heart-synchronized pulsed laser system of claim 1 in which said means for firing includes gate means (70) for inhibiting delivery of said trigger pulse to said laser.

14. The heart-synchronized pulsed laser system of claim 13 in which said means for firing includes

switch means (74) for enabling said gate means to deliver said trigger pulse to said laser.

15. The heart-synchronized pulsed laser system of claim 13 in which said means for firing includes an arming circuit (76) for further inhibiting delivery of said trigger pulse to said laser.

16. The heart-synchronized pulsed laser. system of claim 15 in which said means for firing includes arming switch means (78) for enabling said arming circuit to deliver said trigger pulse to said laser.

17. A method of operating a heart-synchronized pulsed laser comprising the steps of:
generating a trigger pulse in response to the ECG signal of a beating heart to be synchronized with a laser;
positioning the leading edge of the trigger pulse during the contraction and expansion cycle of the heartbeat;
characterized by the steps of
defining the width of the trigger pulse to occur within the duration of said heartbeat cycle of the ECG signal; and
applying the trigger pulse to fire the laser at the time indicated by the trigger pulse position and for the period indicated by the width of the trigger pulse.

Patentansprüche

1. Mit dem Herz synchronisiertes Impuls-Lasersystem (10), das folgende Bestandteile umfaßt:
einen Laser (24);
Einrichtungen (12) zum Abfühlen der Kontraktion und Expansion eines schlagenden Herzens, mit dem der Laser sychronisiert werden soll,
Einrichtungen (18), die auf die Abfühl-Einrichtungen ansprechen und zum Erzeugen eines Trigger-Impulses (20) dienen,
Einrichtungen (32) zum Positionieren der vorauseilenden Flanke des Trigger-Impulses während des Kontraktions- und Expansions-Zyklus des Herzschlags,
dadurch **gekennzeichnet**, daß das System weiterhin folgende Bestandteile umfaßt:
Einrichtungen (34) zum Festlegen der Breite des Trigger-Impulses zum Auftreten während des Herzschlag-Zyklus und
Einrichtungen (22), die auf den Trigger-Impuls (20) reagieren und dazu dienen, den Laser so zu zünden, daß er das schlagende Herz zu dem Zeitpunkt trifft, der durch die Position des Trigger-Impulses angezeigt wird und für eine Zeitdauer, die durch die Breite des Trigger-Impulses angezeigt wird.

2. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 1, bei dem der Laser ein Laserstrahl-Abgabesystem (26, 26a, 28) umfaßt.

3. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 2, bei dem das Laser-Abgabesystem einen gelenkigen Strahl-Abgabearm (26) umfaßt.

4. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 2, bei dem das Laser-Abgabesystem ein faseroptisches Element (26a) umfaßt.

5. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 1, bei dem die Einrichtungen zum Abfühlen der Kontraktion und Expansion Einrichtungen (12) zum Erfassen des Elektrokardiogramm-Signals des schlagenden Herzens umfassen.

6. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 5, bei dem die Einrichtung (12) zum Erfassen des Elektrokardiogramm-Signals des schlagenden Herzens eine Elektrokardiogramm-Einheit ist.

7. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 5, bei dem die Einrichtungen (18) zum Erzeugen eines Trigger-Impulses diesen in Antwort auf die R-Welle des Elektrokardiogramms erzeugen.

8. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 5, bei dem die Einrichtungen (32) zum Positionieren die vorauseilende Flanke des Trigger-Impulses in den Zeitraum zwischen den R- und den T-Wellen des Elektrokardiogramms setzen.

9. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 5, bei dem die Einrichtungen (34) zum Definieren der Impulsbreite die Impulsbreite des Trigger-Impulses in der Periode zwischen den R- und T-Wellen des Elektrokardiogramms definieren.

10. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 5, bei dem die Einrichtung zum Erzeugen eine Markierungsimpuls-Schaltung (50) zum Detektieren eines speziellen Zeitpunktes in einem Herzschlag-Zyklus des Elektrokardiogramm-Signals umfaßt, das einen Markierungsimpuls liefert, der hierfür kennzeichnend ist.

11. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 10, bei dem die Einrichtungen zum Erzeugen weiterhin eine Triggerimpuls-Schaltung (54) umfassen, die auf die Markierungsimpuls-Schaltung (50) antwortet, um einen Trigger-Impuls (20) zu erzeugen, dessen Position im Herzschlag-Zyklus eine Funktion des spezifischen Zeitpunkts im

Zyklus ist, der durch den Markierungsimpuls repräsentiert wird.

12. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 11, bei dem die Triggerimpuls-Schaltung Einrichtungen (88) zum Verzögern des Markierungsimpulses umfaßt, um ihn an einer ausgewählten Stelle bezüglich seiner Anfangsposition im Herzschlag-Zyklus zu positionieren, sowie Einrichtungen (94) um die Dauer des Markierungsimpulses auf eine ausgewählte Zeit einzustellen, um den Trigger-Impuls mit der ausgewählten Position und Breite zu erzeugen.

13. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 1, bei dem die Einrichtung zum Zünden eine Torschaltung (70) zum Sperren der Abgabe des Trigger-Impulses an den Laser umfaßt.

14. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 13, bei dem die Einrichtung zum Zünden eine Schalteinrichtung (74) umfaßt, um die Torschaltung zu aktivieren, um den Trigger-Impuls an den Laser abzugeben.

15. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 13, bei dem die Einrichtung zum Zünden eine Scharfmach-Schaltung (76) für ein weiteres Hemmen der Abgabe des Trigger-Impulses an den Laser umfaßt.

16. Mit dem Herz synchronisiertes Impuls-Lasersystem nach Anspruch 15, bei dem die Einrichtung zum Zünden eine Scharfmach-Schalteinrichtung (78) umfaßt, um es der Scharfmach-Schaltung zu ermöglichen, den Trigger-Impuls an den Laser abzugeben.

17. Ein Verfahren zum Betreiben eines mit dem Herz synchronisierten Impuls-Lasers, das folgende Schritte umfaßt:
Erzeugen eines Trigger-Impulses in Antwort auf das Elektrokardiogramm-Signal eines schlagenden Herzens, mit dem der Laser synchronisiert werden soll,
Positionieren der Vorderflanke des Trigger-Impulses während des Kontraktions- und Expansions-Zyklus des Herzschlages,
dadurch **gekennzeichnet,** daß weiterhin folgende Schritte vorgesehen sind:
Definieren der Breite des Trigger-Impulses, der innerhalb der Dauer des Herzschlag-Zyklus des Elektrokardiogramm-Signals auftreten soll und
Anlegen des Trigger-Impulses zum Zünden des Lasers in dem Zeitpunkt, der durch die Position des Trigger-Impulses angezeigt ist und für eine Zeitdauer, die durch die Breite des Trigger-Impulses dargestellt ist.

Revendications

1. Système (10) de laser pulsé synchronisé avec le coeur comprenant :
un laser (24);
des moyens (12) pour détecter la contraction et la dilatation d'un coeur qui bat pour être synchronisé avec le laser ;
des moyens (18) sensibles auxdits moyens pour détecter, pour créer une impulsion de déclenchement (20);
des moyens (32) pour positionner le bord avant de ladite impulsion de déclenchement pendant le cycle de contraction et de dilatation du battement du coeur,
caractérisé en ce que ledit système comprend en outre :
des moyens (34) pour définir la largeur de l'impulsion de déclenchement pour qu'elle se produise pendant ledit cycle du battement de coeur ; et
des moyens (22) sensibles à ladite impulsion de déclenchement (20), pour actionner ledit laser pour qu'il percute le coeur qui bat au temps indiqué par la position de l'impulsion de déclenchement et pendant la période indiquée par la largeur de l'impulsion de déclenchement.

2. Système de laser pulsé synchronisé avec le coeur selon la revendication 1, dans lequel ledit laser comprend un système pour délivrer un faisceau laser (26, 26a, 28).

3. Système de laser pulsé synchronisé avec le coeur selon la revendication 2, dans lequel ledit système pour délivrer le laser comprend un bras articulé (26) pour délivré un faisceau.

4. Système de laser pulsé synchronisé avec le coeur selon la revendication 2, dans lequel ledit système pour délivré le laser comprend un élément à fibres optiques (26a).

5. Système de laser pulsé synchronisé avec le coeur selon la revendication 1, dans lequel lesdits moyens pour détecter la contraction et la dilatation comprennent des moyens (12) pour détecter le signal de l'électrocardiogramme du coeur qui bat.

6. Système de laser pulsé synchronisé avec le coeur selon la revendication 5, dans lequel lesdits moyens (12) pour détecter le signal de l'électrocardiogramme du coeur qui bat est une unité d'électrocardiogramme.

7. Système de laser pulsé synchronisé avec le coeur selon la revendication 5, dans lequel lesdits moyens (18) pour générer génèrent une impulsion de déclenchement en réponse à l'onde R de l'électrocardiogramme.

8. Système de laser pulsé synchronisé avec le coeur selon la revendication 5, dans lequel lesdits moyens (32) pour positionner placent le bord avant de ladite impulsion de déclenchement dans la période entre les ondes R et T de l'électrocardiogramme.

9. Système de laser pulsé synchronisé avec le coeur selon la revendication 5, dans lequel lesdits moyens (34) pour définir définissent la largeur de l'impulsion de ladite impulsion de déclenchement dans la période entre les ondes R et T de l'électrocardiogramme.

10. Système de laser pulsé synchronisé avec le coeur selon la revendication 5, dans lequel lesdits moyens pour générer comprennent un circuit d'impulsion de marquage (50) pour détecter un temps spécifique dans le cycle de battement du coeur du signal de l'électrocardiogramme en fournissant une impulsion de marquage représentative de celui-ci.

11. Système de laser pulsé synchronisé avec le coeur selon la revendication 10, dans lequel lesdits moyens pour générer comprennent en outre un circuit d'impulsion de déclenchement (54) sensible audit circuit d'impulsion de marquage (50) pour fournir une impulsion de déclenchement (20) dont la position dans le cycle de battement du coeur est une fonction dudit temps spécifique dans le cycle représenté par ladite impulsion de marquage.

12. Système de laser pulsé synchronisé avec le coeur selon la revendication 11, dans lequel ledit circuit d'impulsion de déclenchement comprend des moyens (88) pour retarder ladite impulsion de marquage pour la situer dans une position choisie par rapport à sa position initiale dans le cycle de battement du coeur, et des moyens (94) pour ajuster la durée de l'impulsion de marquage à un temps choisi pour créer ladite impulsion de déclenchement de la position choisie et de la largeur choisie.

13. Système de laser pulsé synchronisé avec le coeur selon la revendication 1, dans lequel lesdits moyens pour actionner comprennent des moyens de porte (70) pour empêcher l'envoi de ladite impulsion de déclenchement audit laser.

14. Système de laser pulsé synchronisé avec le coeur selon la revendication 13, dans lequel lesdits moyens pour actionner comprennent des moyens de commutation (74) pour permettre auxdits moyens de porte d'envoyer ladite impulsion de déclenchement audit laser.

15. Système de laser pulsé synchronisé avec le coeur selon la revendication 13, dans lequel les moyens pour actionner comprennent un circuit d'armement (76) pour empêcher de manière supplémentaire l'envoi de ladite impulsion de déclenchement audit laser.

16. Système de laser pulsé synchronisé avec le coeur selon la revendication 15, dans lequel lesdits moyens pour actionner comprennent des moyens de commutation d'armement (78) pour permettre audit circuit d'armement d'envoyer ladite impulsion de déclenchement audit laser.

17. Procédé pour faire fonctionner un laser pulsé synchronisé avec le coeur comprenant les étapes de :

générer une impulsion de déclenchement en réponse à un signal d'électrocardiogramme d'un coeur qui bat pour être synchronisé avec un laser ;

positionner le bord avant de l'impulsion de déclenchement pendant le cycle de contraction et de dilatation du battement du coeur ;

caractérisé par les étapes de

définir la largeur de l'impulsion de déclenchement pour qu'elle se produise pendant la durée dudit cycle de battement du coeur du signal de l'électrocardiogramme ; et

appliquer l'impulsion de déclenchement pour actionner le laser au temps indiqué par la position de l'impulsion de déclenchement et pendant la période indiquée par la largeur de l'impulsion de déclenchement.

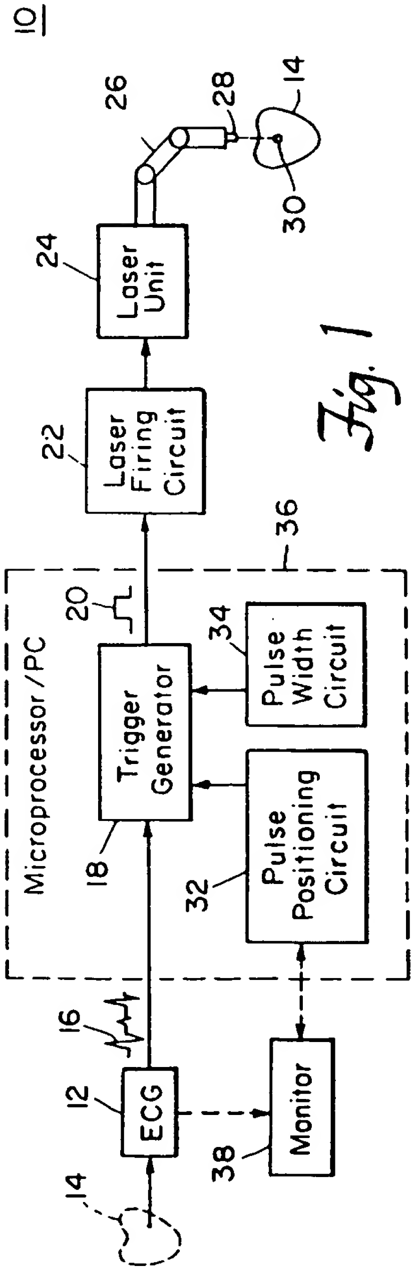
10
Microprocessor/PC
ECG
Monitor
Trigger Generator
Pulse Positioning Circuit
Pulse Width Circuit
Laser Firing Circuit
Laser Unit
12
14
16
18
20
22
24
26
28
30
32
34
36
38

Fig. 1

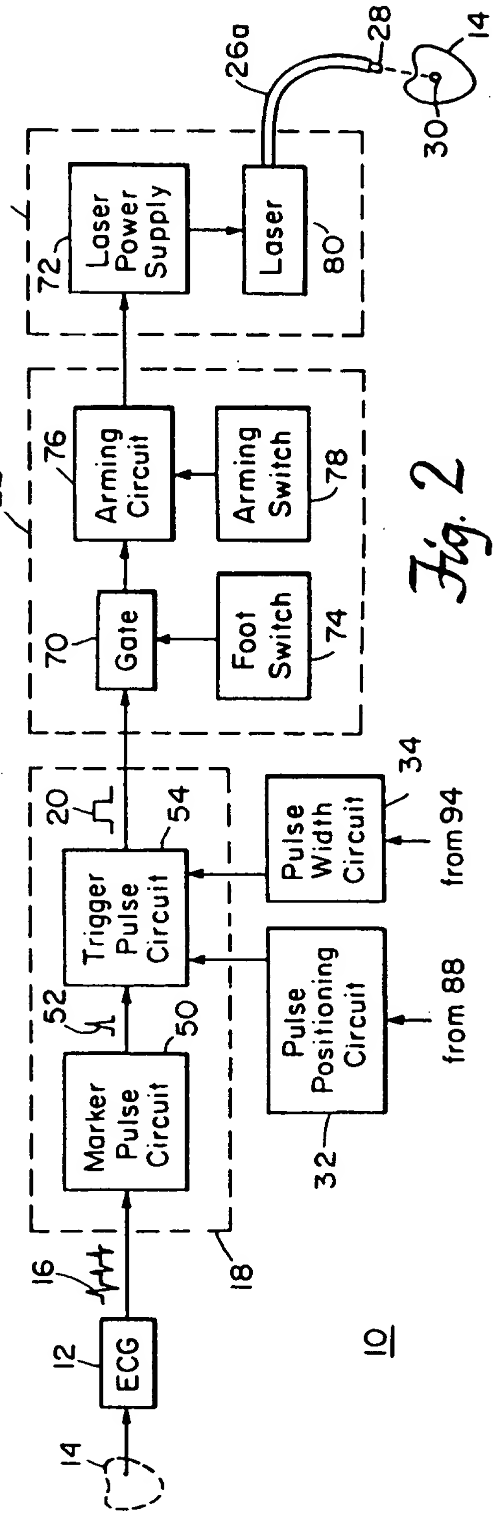
10
ECG
Marker Pulse Circuit
Trigger Pulse Circuit
Pulse Positioning Circuit
from 88
Pulse Width Circuit
from 94
Gate
Foot Switch
Arming Circuit
Arming Switch
Laser Power Supply
Laser
12
14
16
18
20
22
24
26a
28
30
32
34
50
52
54
70
72
74
76
78
80

Fig. 2

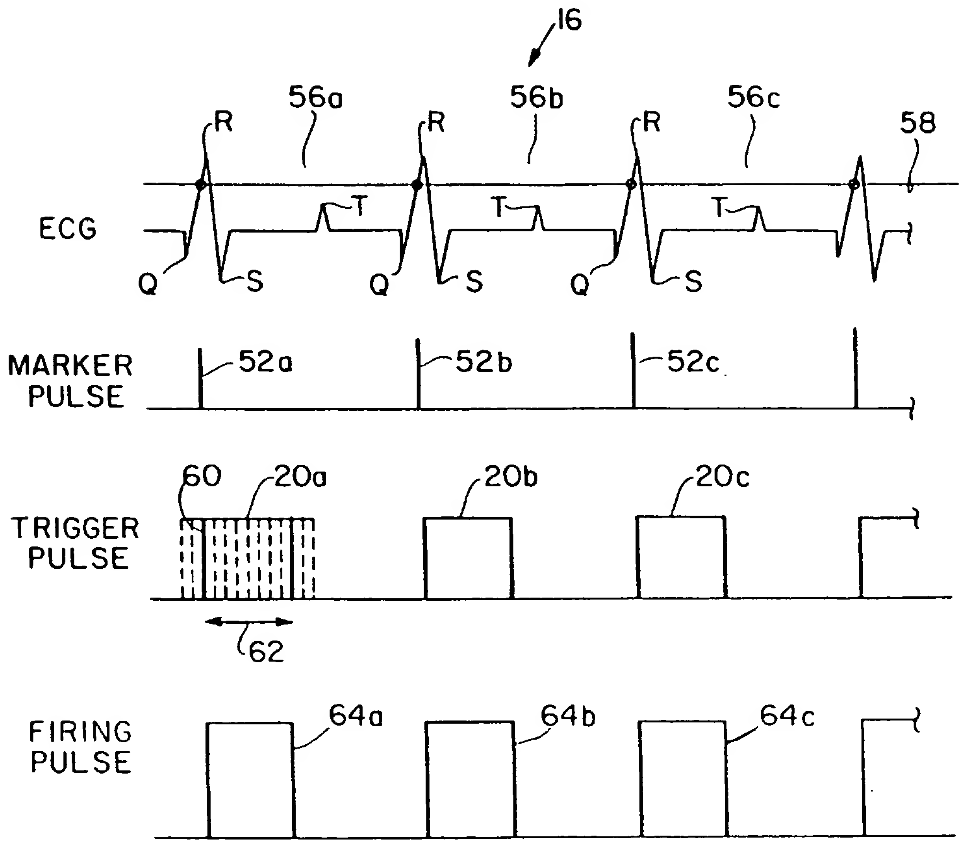
16
56a
56b
56c
58
R
R
R
T
T
T
ECG
Q
S
Q
S
Q
S
MARKER PULSE
52a
52b
52c
60
20a
20b
20c
TRIGGER PULSE
62
FIRING PULSE
64a
64b
64c

Fig. 3

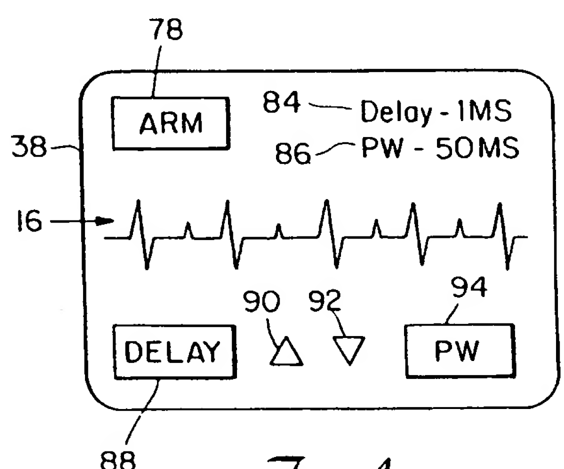
78
ARM
84
Delay - 1MS
86
PW - 50MS
38
16
90
92
94
DELAY
PW
88

Fig. 4

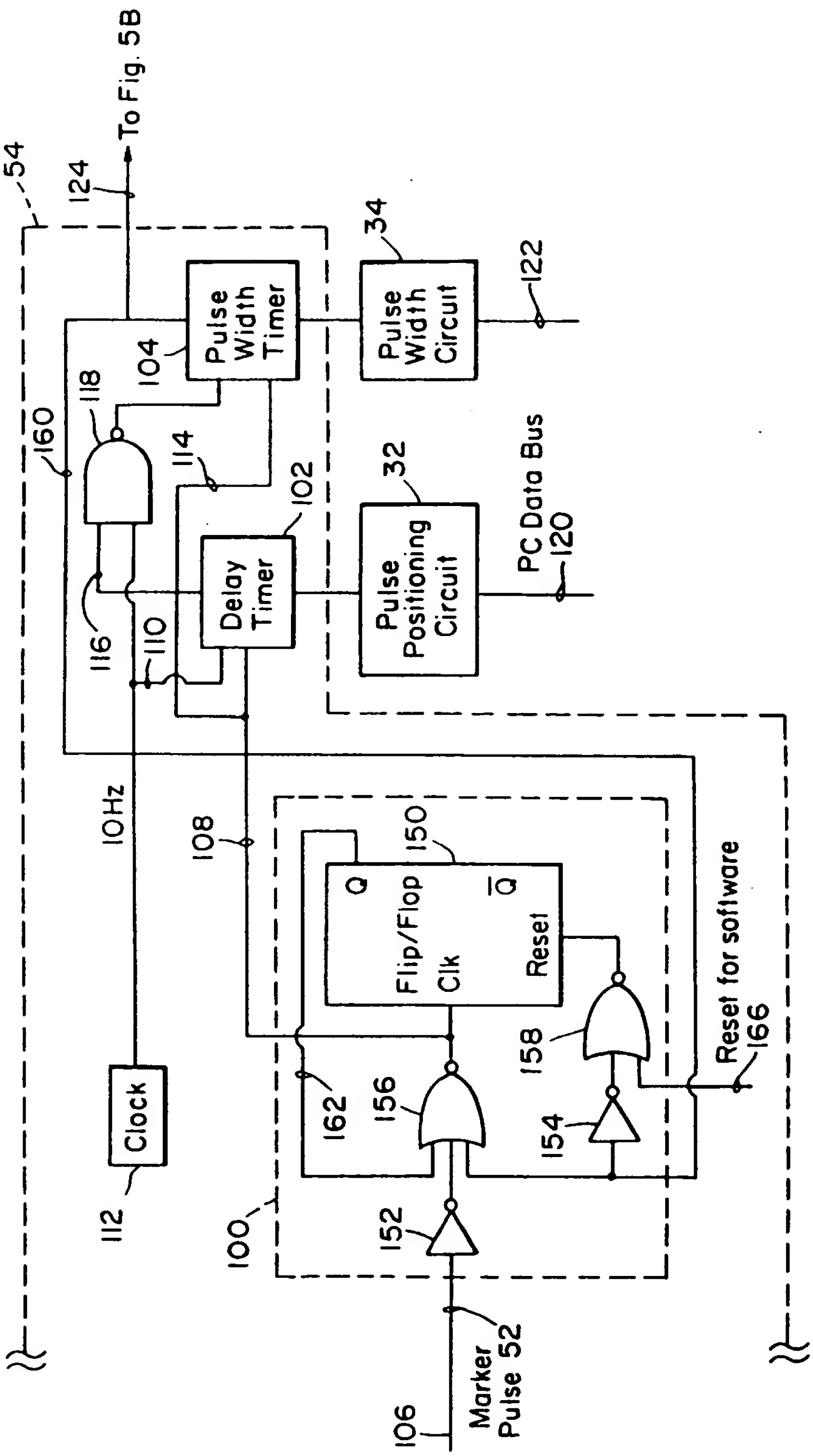
54
124
To Fig. 5B
34
122
Pulse Width Circuit
Pulse Width Timer
104
118
160
114
102
32
PC Data Bus
120
Pulse Positioning Circuit
Delay Timer
116
110
10Hz
108
150
Q
Flip/Flop
Clk
Reset
$\overline{Q}$
158
Reset for software
166
162
156
154
Clock
112
100
152
Marker Pulse 52
106

Fig. 5A

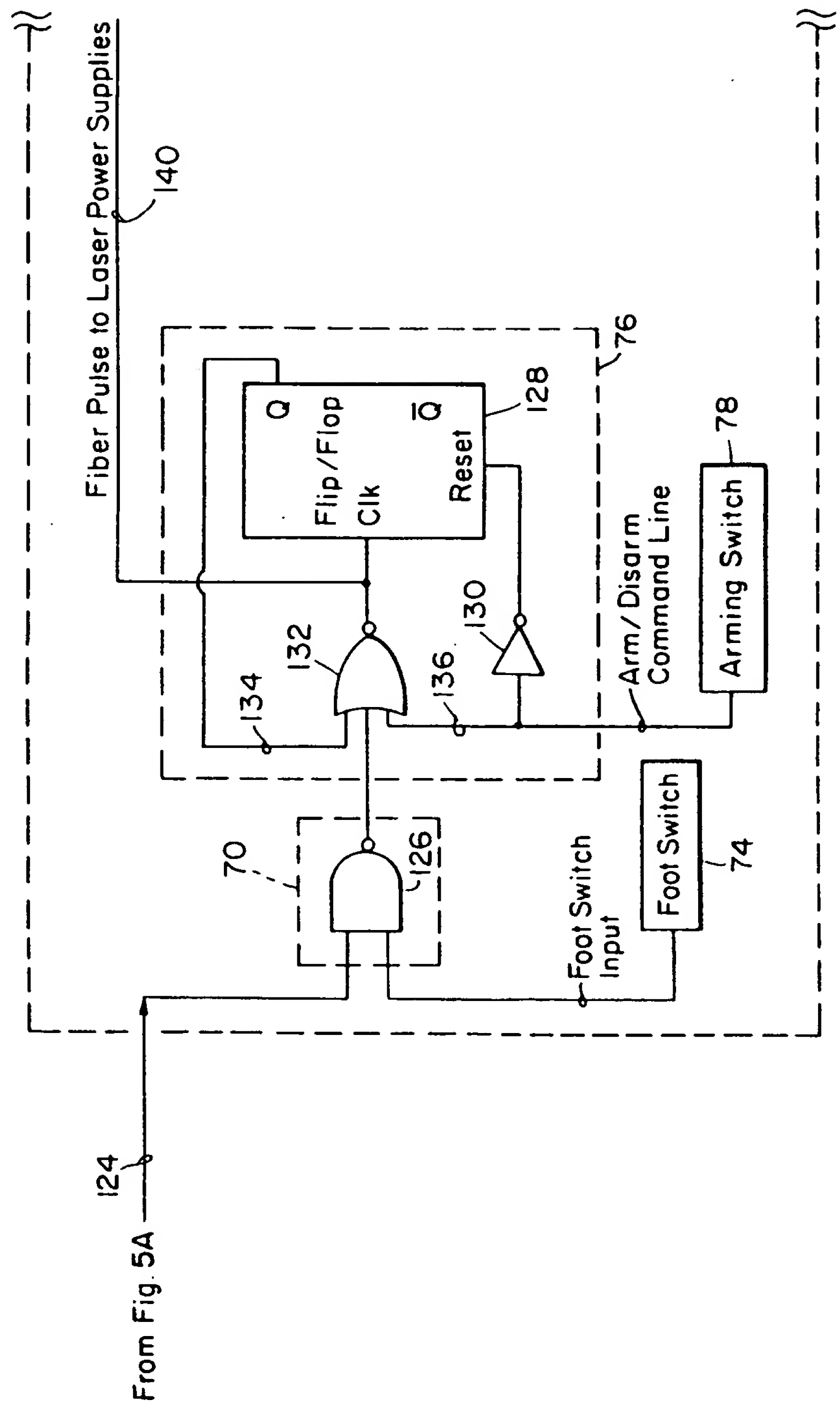
Fiber Pulse to Laser Power Supplies
140
76
Q
Flip/Flop
Clk
Q̄
Reset
128
132
130
134
136
Arm/Disarm Command Line
Arming Switch
78
70
126
Foot Switch Input
Foot Switch
74
124
From Fig. 5A

Fig. 5B